Corrosion Behavior of Bottom Plates of A potable Water Storage Tank

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الخلاصة

هذا البحث يوصف سلوك التآكل الحاصل لقعر خزان ماء الشرب بعد أربعة عشر عاما مـن الاستخدام , وبعد فحصة لوحظ تفقع طبقة الصبغ وبقع الصدأ لقعر الخزان . . أثناء الفحـص لـوحظ ثقوب وتنقر عميق . تم إعادة صبغة بعد قصفة بالرمل للتنظيف و لإزالة بقايا نواتج التآكل كعلاج .من جهة أخرى أجريت فحوصات لا تدميرية (المغناطيسية ,فوق الصوتية) لكشف التآكل غيـر المنظـور وتقييم لعمل منظومة الحماية السالبة . أن سلوك التآكل يعزى إلى سيلان الماء وأحتجازة تحت الخزان على طول محيطة وفشل طلاء الأيبوكسي .

Abstract

This paper describes the investigation of a corrosion behavior of bottom Plates of a potable water storage tank . The tank was internally inspected for the first time after fourteen years of service. Paint blisters and rust spots were observed on the bottom plates. Sand blasting and repainting the bottom plates and shell plates were to be used as a remedial work .

However, during the sand blasting, holes and deep pitting were observed on the bottom plates. On-site visual inspection, magnetic flux leakage (MFL) inspection, ultrasonic testing (UT), and evaluation of the external cathodic protection (CP) system were used in the failure analysis. The failure is attributed to the ingress of water and its impoundment under the tank bottom along the periphery inside the ring wall and failure of water side epoxy coating.

Keyword: Coating thickness , Corrosion failure analysis , Nondestructive examination .

1-Introduction

Coating and cathodic protection (CP) are both engineering techniques with the primary purpose of mitigating and preventing corrosion. To obtain maximum corrosion resistance from the combination of a coating and CP, a number of factors must be taken into consideration.

Any coating lacking resistance to alkalis, electroendosmosis, proper adhesion, and optimum coating thickness are likely to fail by blistering under CP. The results of both laboratory testing and actual use of the combined system have shown that coating thickness and cathodic protection potential (CPP) are very important when a coating is to be used with CP [1,2,3]. Results of cathodic disbonding tests have indicated that, in general, thicker coatings show better results. Furthermore, an increase in the value of CPP from – 850 mV versus $Cu/CuSO_4$ reference cell resulted in early blistering [4,5].

The severity of underside corrosion is directly related to the corrosivity of the soil, which depends on a number of soil parameters, for example, pH; resistivity; redox potential; and moisture, sulfides, sulfates, and chlorides content. Stray direct currents (DC) or induced alternating current (AC) sources can accelerate soil corrosion [6,7].

2-Experimental Works

2-1-Background of Failure

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The bottom plates of the potable water tank failed after approximately fourteen years of service. There are three other identical potable water tanks in the neighborhood of the failed tank. The bottom plate topside that is in direct contact with water has a coating of Hempadur Multi- Strength 3553 (Hempel A/S). The tank is cathodically protected (impressed current) from the top (waterside) as well as the underside (soil side). When the tank was opened for the first time for internal inspection, some paint blisters and rust spots were observed on the bottom plates and first to third shell plates from the bottom. Sand blasting and repainting of the affected plates were attempted as a remedial measure. However, during the sand blasting, holes and deep pitting were observed on the bottom plates. The detail of the tank is described in Table 1.

The cause of the failure of bottom plates has been investigated through a physical examination of the bottom plates. Inspection by MFL and UT was carried out to determine the extent of corrosion (plate thickness loss).

The evaluation of external CP systems of the failed and the neighboring tanks were carried out to establish the effectiveness of the CP system and to observe the possible effect of stray current in the failure.

2-2-Visual examination

The samples of the bottom plate obtained from two different locations are shown in the as-received condition in Figures. 1 and 2. A visual examination of the topside of the plate, cut from a location near the annular plate, showed holes and deep pits of varying depth (Fig. 1a). The underside of the plate was found to be heavily corroded (Fig. 1b). Figure 2 shows the bottom plate sample cut from a location far away from the annular plate. Initiation and propagation of pits from water side can be seen. However, the underside of the bottom plate sample does not show any corrosion.

A detailed inspection of the bottom plate revealed that pits and holes were confined within a 1 m area of the junction of the annular and bottom plate and mainly concentrated over and/or near the weld junction of two sections of bottom plates. A gap between backfill and the bottom plates was also visualized around the same area along the periphery of the tank.

Magnetic flux leakage (MFL) inspection A 100% MFL inspection was carried out on the bottom plates to determine corrosion, pitting, and wall thickness loss. Before starting the scanning of the bottom plates, the scanner was rolled over a calibration plate of similar material and thickness having artificial defects.

The bottom plates were divided into several tracks of 250 mm widths and each track was individually scanned and corrosion data was collected. Due to lack of accessibility for MFL scanning of the annular plates, the sumps and the area closed to the roof supports were scanned by UT. The MFL inspection on the bottom plates revealed:

1. Holes were noted on 18 bottom plates.
2. Eight locations showed underside corrosion (wall thickness loss) greater than 50%.
3. The area showing holes and above 50% wall loss is confined within a 1 m area of the junction of the annular and bottom plate, along the periphery of the tank.
4. Six sumps and annular plates, scanned by UT, did not show significant wall loss.

Evaluation of CP system to establish the effectiveness of the CP system of the failed tank and to find out the possible role of stray current in the failure, evaluation of external CP systems of the failed as well as neighboring tanks were carried out. The potential readings were measured in the following sequence:

1. Readings of the failed tank when the CP systems of the neighboring and the failed tanks were on .
2. Readings of the neighboring tank when the CP systems of the failed and the neighboring tanks were on .
3. Readings of the failed tank after turning off its CP system .
4. Readings of the neighboring tank after turning off the CP system of the failed tank .
5. Readings of the failed tank after three days of turning off its CP system.

The measurement was continued for an extended period. To confirm the current pickup by the grounding system of the tank, the current return through the grounding cables was also measured when the CP system of the failed tank was on. Analyzing the readings, these conclusions were drawn:

1. The CP system of the failed tank is functioning correctly and adequately protecting the tank.
2. The CP system of the failed tank is integrated with the CP systems of the neighboring tanks and affecting each other.

All the tanks are interconnected through the common grounding grid and inlet/outlet pipes. This was reconfirmed by interrupting the four transformer rectifiers together and observing the effect on the tank potentials.

3. When the CP system of the failed tank was turned off, 100–300 mV of positive potential shift was observed, but the potential level of the tank was still indicating full protection level. This is because of the protection through the CP system of the neighboring tanks and not because of any stray current. Similarly, there was a positive potential in the readings of the neighboring tanks when the CP system of the failed tank was switched off. This also confirms the integration of the CP system.
4. A substantial amount of current is picked up by the grounding grid and by other tanks, as was indicated by return current through grounding cables. The current measured was the net current due to CP systems of the failed and other neighboring tanks.
5. The potential readings measured outside the ring wall (potential of the grounding grids) indicated full protection even after turning off the CP system of the failed tank. This again confirmed the integration of the CP systems of all the tanks.

3-Results and Discussion

The tank bottom plates are in contact with two different corroding environments, that is, potable water on the topside and soil on the underside. The bottom plate underside is protected against corrosion by the CP system, whereas the topside is protected by a combination of epoxy coating and CP. A study of a sample of the bottom plate cut from a location near the annular plate revealed severe underside corrosion with holes and deep pitting initiating and propagating from the topside. The sample of the bottom plate cut from a location far away from the annular plate revealed pitting originating and propagating from the topside with little underside corrosion. This confirms the initiation of corrosion from water as well as soil with varying degree.

Considering the underside corrosion of the plates, the MFL inspection report and visual examination of the bottom plates revealed holes and severe underside corrosion (wall loss) with deep pitting initiating and propagating from waterside. The holes and heavy wall loss are mainly confined along the periphery inside the ring wall. The severity of underside corrosion is directly related to the corrosivity of the soil, which depends upon a number of soil parameters such as pH; resistivity; redox potential; and moisture, sulfides, sulfates, and chlorides content [6,7].

The stray DC or induced AC sources can also influence soil corrosion and have been responsible for many such failures [7,8] . To establish the effectiveness of the CP system of the failed tank and to find out the possible role of stray current in the failure, evaluation of external CP systems of the failed as well as neighboring tanks were carried out.

The result of the evaluation confirmed the integration of the CP systems of all the tanks and ruled out the role of stray current effect in the failure.

Considering the corrosion on the topside of the plates, it was determined that the holes and deep pits were caused due to the failure of epoxy coating applied over the topside of the bottom plates of the water tank. In the absence of a detailed examination of the failed coating and analysis of the cathodic deposits in the pits and blisters, it is difficult to ascertain the actual cause of the coating failure at this stage of the investigation. However, the probable causes of the coating failure can be predicted.

Though the blistering in the coating may be as a result of the lack of any of the essential coating properties required when used in combination with the CP system, a definite pattern of the failure gives some speculation about the possible role of the internal CP system in the blistering. An examination of the total applied cathodic current and the distribution of cathodic current to different anodes over a period of time indicated some malfunctioning in the internal CP system [9,10].

The blistering in the coating led to the formation of a number of electrolytic cells on the surface of the bottom plates. The anode of this cell consisted of the minute exposed area of the metal, and the cathode was the large coated area. The large potential difference of this passive active cell accounted for the rapid corrosion at the small anode.

This caused the formation of pits. The coating surrounding the anode and the activating property of corrosion products within the pits accounted for the tendency of corrosion to penetrate the metal rather than spread along the surface; this finally led to the formation of pits of varying depths. Some of the pits near the periphery resulted in through holes as a result of considerable wall thickness loss due to severe underside corrosion.

The observed holes and heavy wall loss along the tank periphery are due to underside corrosion as a result of water ingress under the tank bottom. The type of construction favored the ingress of rainwater or cleaning water through the gaps under the tank bottom and ring wall. The water accumulated near the periphery inside the ring wall, and with time the backfill settled down creating voids between the tank bottom and the backfill. Once the accumulated water settled down, the underside of the bottom plate in this area remained wet and started corroding due to local corrosion cell formation [11].

The heat-affected zone (HAZ) near the weld area provided the ideal site for the initiation of corrosion [12]. The CP system in this area remained ineffective due to the non-availability of the electrolyte. Further, some of the pits initiating and propagating from the water side along the periphery resulted in through holes due to considerable loss of wall thickness in the corresponding areas as a result of underside corrosion. The holes in the bottom plate led the high conductivity water to come in contact with the underside of the plate, thus causing heavy damage over a period of time.

4-Conclusions

1. The corrosion of the bottom plates initiated from the underside as well as the topside.
2. The heavy underside corrosion is initiated due to water ingress and its accumulation under the tank bottom. The accumulated water caused the settlement of the backfill making CP system in that area ineffective.
3. The topside corrosion initiated as a result of the blistering in the coating, which led to localized attack and resulted in the deep pitting. The blistering in the coating may be due to malfunctioning of the internal CP system.
4. The leaked potable water, through holes, further contributed in accelerating the underside corrosion.
5. Inspection by MFL revealed heavy underside corrosion and holes along the periphery of the tank inside the ring wall.
6. The evaluation of the external CP system confirmed the integration of the CP systems of all the tanks and ruled out the role of stray current on the underside corrosion. The external CP system of the failed tank was found to be operational and adequately protecting the tank.

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Table 1 Information data about the flat bottom water tank

Diameter	96,800 mm
Height	20,000 mm
Design code	API 650 9th Edition 1993—Appendix E
Capacity	140,000 m^3
Product	Potable water
Product specific gravity	1.00
Maximum operating temperature	60˚C
Minimum design metal temperature	0˚C
Design pressure	Atmospheric
Design vacuum	Atmospheric
Corrosion	allowances
Shell	0 mm
Bottom plates	0 mm
Roof plates	0 mm
Roof framing	0 mm
Wind design per AP I 650 Materials	162 km/h
Shell rings 1 to 7	A 537 class 2
Annular plates	A 283-C
Bottom plates	A 283-C
Roof plates	A 283-C
Columns A312-TP	316L or equivalent
Structurals—external	A 36
Structurals—internal	A 479-316L or equivalent
Piping—external	A 106-B or m/f A 537 class 2
Piping—internal	A312-TP 316L or equivalent
Plate thickness	
Annular plate	16 mm
Bottom plate	6.35 mm (lap welded bottom)
Type of CP	
External	Impressed current
Internal	Impressed current
Bottom topside (work side)	paint dry film thickness (DFT)
Primer	Hempadur 1559, DFT 40 μm
Second coat	Hempadur 3553 (light gray), DFT , 200 μm
Top coat	Hempadur 3553 (off white), DFT , 200 μm

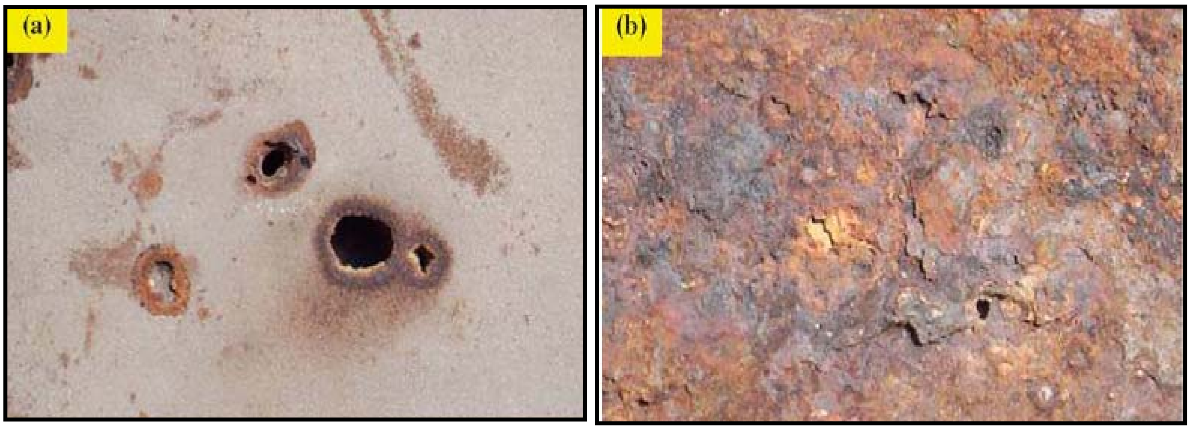

Fig. 1 (a) Topside of the bottom plate sample, cut from a location near the annular plate, in the as-received condition showing pit and holes. 1X. (b) Underside of the same bottom plate sample in the as-received condition showing heavy corrosion. 1X.

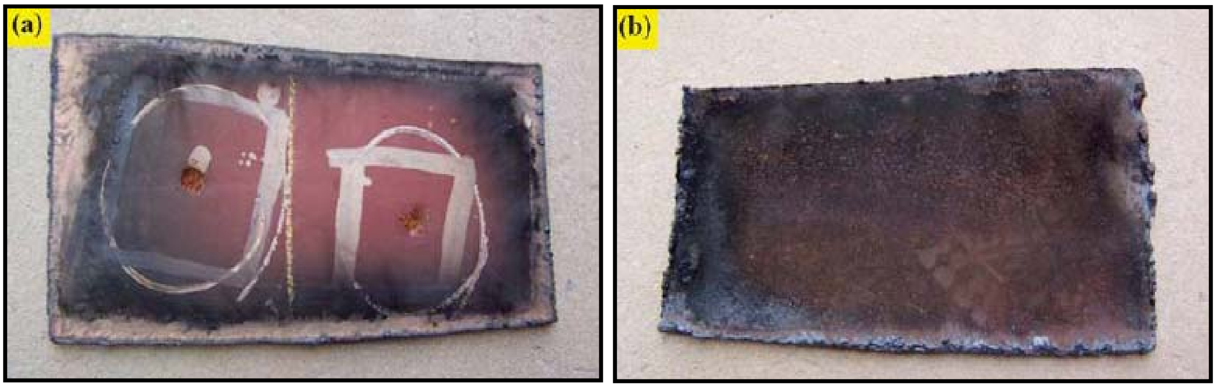

Fig. 2 (a) Topside of the bottom plate sample, cut from a location far away from annular plate, in as-received condition showing only pits 0.35X. (b) Underside of the same bottom plate sample in the as received condition showing no corrosion 0.35X.